

Body Mass Index and use and costs of primary care services among women aged 55 to 79 years in England: a cohort and linked data study

Seamus Kent MSc¹, Susan A Jebb PhD², Alastair Gray PhD¹, Jane Green DPhil³, Gillian Reeves DPhil³, Valerie Beral FRS³, Borislava Mihaylova DPhil^{1,4*}, Benjamin J Cairns PhD^{3,5*} on behalf of the Million Women Study collaborators[¥]

Running title

BMI and the use and costs of primary care services

Affiliations

¹ Health Economics Research Centre, Nuffield Department of Population Health, University of Oxford

² Nuffield Department of Primary Care Health Sciences, University of Oxford

³ Cancer Epidemiology Unit, Nuffield Department of Population Health, University of Oxford

⁴ Centre for Primary Care and Public Health, Barts and The London School of Medicine and Dentistry, Queen Mary University of London

⁵ Medical Research Council Population Health Research Unit, Clinical Trial Service Unit & Epidemiological Studies Unit, Nuffield Department of Population Health, University of Oxford

*These authors contributed equally to the work

¥Collaborators listed at the end of the manuscript

Addresses

^{1,3} Richard Doll Building, Old Road Campus, Oxford, OX3 7LF

² Radcliffe Observatory Quarter, Woodstock Road, Oxford, OX2 6GG

⁴ Barts and The London School of Medicine and Dentistry, Yvonne Carter Building, London E1 2AB

⁵ Big Data Institute, Old Road Campus, Oxford, OX3 7LF

Corresponding author:

1 Seamus Kent
2 Richard Doll Building, Old Road Campus, Oxford, OX3 7LF, UK
3 Email: seamus.kent@ndph.ox.ac.uk
4 Phone: +44 1865 289381
5

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20 relationships or activities that could appear to have influenced the submitted work.

1 **ABSTRACT**

2 **Background**

3 Excess weight is associated with poor health and increased healthcare costs. There are no
4 reliable data describing the association between BMI and the use and costs of primary care
5 services in the United Kingdom.

6 **Methods**

7 Among 69,440 participants in the Million Women Study with primary care records in the
8 Clinical Practice Research Datalink between April 2006 (mean age 64 years) and March
9 2014, the annual rates and costs of their primary care consultations, prescription medications,
10 and diagnostic and monitoring tests were estimated in relation to their self-reported body-
11 mass index (BMI) at recruitment in 1996-2001 (mean age 56 years). Associations of BMI
12 with annual costs were projected to all women in England aged 55-79 years in 2013.

13 **Results**

14 Over an average follow-up of 6.0 years, annual rates and mean costs were lowest for women
15 with a BMI of 20 to $<22.5\text{kg/m}^2$ for consultations (7.0 consultations, 99% CI 6.8-7.1; £288,
16 £280-£295) and prescription medications (27.0 prescribed items, 26.0-27.9; £227, £216-
17 £237). Above 20 kg/m^2 , a 2kg/m^2 higher BMI (a 5kg change in weight for a woman of
18 average height) was associated with 5.2% (4.8-5.6) and 9.9% (9.2-10.6) higher mean annual
19 consultation and prescription medication costs, respectively. Annual rates and mean costs of
20 diagnostic and monitoring tests were similar for women with different BMIs. Among all
21 women aged 55-79 years in England, excess weight accounted for an estimated 11%
22 (£229million/£2.2billion) of all consultation costs and 20% (£384million/£1.9billion) of all

1 prescription medication costs, of which 27% were for diabetes drugs, 19% for circulatory
2 system drugs, and 13% for analgesics.

3 **Conclusions**

4 Excess body weight is associated with higher use and costs of primary care services among
5 women in England. Reducing the prevalence of excess weight could improve the health of
6 women and reduce pressures on primary care.

7

1 INTRODUCTION

2 The prevalence of overweight and obesity (body mass index [BMI] $\geq 25\text{kg/m}^2$) has increased
3 substantially in many countries in recent decades. Between 1975 and 2015 its prevalence
4 among adults in the United Kingdom (UK) increased from 45% to 68% in men and from 33%
5 to 58% in women.¹ Excess weight is associated with an increased incidence of conditions
6 including type-2 diabetes, vascular diseases, osteoarthritis, depression, and certain cancers, as
7 well as with higher mortality.²⁻⁴

8 A recent systematic literature review reported that overweight and obesity were associated
9 with higher costs for major healthcare services, with the greatest relative increase for
10 medications, followed by inpatient care, and then ambulatory care.⁵ Using data on over one
11 million women in the UK, higher BMI was shown to be strongly associated with higher
12 annual rates and costs of hospital admissions, overall and for a range of health conditions.⁶
13 However, previous studies of primary healthcare services have generally been based on
14 small-to-moderate numbers of participants, and are mostly from the United States (US), with
15 no reliable evidence from the UK. It is unclear how well these results translate to the UK
16 given the large differences in medication prices,⁷ and the role of primary healthcare in the UK
17 in determining access to most specialist care.⁸

18 Using individual participant data from a large cohort of women in England linked to routinely
19 collected primary care records, we describe and quantify the relationship between body mass
20 index and the use and costs of primary care services. This also provides insights into how
21 much of the morbidity experienced by this group of women is potentially avoidable.

1 **SUBJECTS AND METHODS**

2 **Million Women Study**

3 Between 1996 and 2001, 1.25 million women in England and 120,000 in Scotland aged 50-64
4 years were recruited into the Million Women Study (MWS) through National Health Service
5 (NHS) breast screening centres. Women who were invited to breast screening and to join the
6 MWS were sent a study questionnaire with their invitation, which included questions about
7 anthropometric, demographic, health, and other personal characteristics. In total around one-
8 quarter of UK women in the eligible age range during recruitment participated in the study.
9 Information on data access for the Million Women Study is available at the study website.

10 **Linkage to health records**

11 For women recruited in England, information was sought on death, emigration, and cancer
12 registrations from NHS Central Registers, hospital admissions from Hospital Episode
13 Statistics, and primary care records from the Clinical Practice Research Datalink (CPRD).
14 Participants were linked to medical records using their unique NHS identification number,
15 age, sex, and postcode.

16 CPRD collates longitudinal primary care medical records for around 7% of the UK
17 population. Clinical data are recorded using version-2 Read codes, a hierarchical clinical
18 classification system used in the UK,⁹ and prescriptions by the product name and British
19 National Formulary (BNF) paragraph code, which provides information on prescribing and
20 pharmacology for medications available on the UK NHS.¹⁰

21 Information for 101,836 participants in the MWS were successfully linked to the CPRD
22 GOLD database, and their primary care records up to January 2014 were extracted. These

1 participants were largely similar to other participants not registered in CPRD-participating
2 practices (Table S1). For the purpose of the present analysis, we excluded: 4 women with
3 unknown vital status; 6503 women whose primary care records were flagged as of poor
4 quality by CPRD (83% of whom had only a temporary registration in the practice); 2133
5 women with registration gaps in their medical records; and, 6073 women whose follow-up in
6 CPRD ended before recruitment into the Million Women Study or before the date on which
7 the data from their general practitioner's practice was judged to be of up-to-standard quality
8 according to CPRD.

9 In our main analysis we also excluded: 1473 women with a recorded diagnosis of cancer
10 (other than non-melanoma skin cancer) before recruitment; 4560 women for whom height or
11 weight data were not available from the MWS recruitment questionnaire; 857 women with a
12 BMI $<18.5 \text{ kg/m}^2$; and 10793 women for whom no data were recorded in CPRD beyond
13 March 2006. Follow-up data prior to April 2006 were excluded from the main analysis
14 because of the major expansion of the NHS's primary care Quality and Outcomes Framework
15 (QOF) in April 2006, which may have influenced clinical practice.⁸ Following these
16 exclusions, 69440 women contributed person-years of data to analyses from April 2006 (or
17 the date from which the practice to which they belonged was considered up-to-standard by
18 CPRD, if later), until the earliest of their date of death, emigration, or 27 January 2014, the
19 last date of CPRD data available for the present study.

20 **Ethical approval**

21 Ethical approval for the Million Women Study was provided by the Oxford and Anglia
22 Multi-Centre Research Ethics Committee and participants gave signed consent for follow-up

1 through their medical records. The use of CPRD data for this study was approved by the
2 CPRD Independent Scientific Advisory Committee.

3 **Categorisation and costing of primary care services**

4 We included all consultation records for the participants relating to a face-to-face surgery or
5 clinic visit, home visit, out-of-hours visit, or telephone consultation, performed by a general
6 practitioner (GP; a primary care doctor), a nurse, or allied health or social care professional
7 (Table S2). Monitoring and diagnostic tests that are routinely performed as part of a standard
8 consultation (e.g. lung capacity or blood pressure tests) were excluded since their costs are
9 included in the costs of consultations. Average NHS costs (in 2016 prices) were applied to
10 other categories of consultations (Table S3) and tests (Table S4).^{11,12}

11 Average costs per prescription item at the BNF paragraph level (Table S5) were calculated
12 from the 2016 NHS Prescription Cost Analysis,¹³ and were applied to each prescription item
13 issued in CPRD based on the BNF paragraph recorded by the GP. Therapies with
14 unrecognised BNF codes in CPRD largely relate to devices and appliances, and an average
15 cost across all such codes was applied.

16 Each prescription item was uniquely allocated to one of eighteen categories of ‘therapeutic
17 use’ corresponding to each of the fifteen standard BNF chapters, plus analgesics, drugs in
18 diabetes, and dressings and appliances. For medications of the circulatory system, medication
19 use was further categorised by BNF section (e.g. lipid-regulating drugs).

20 **Statistical analysis**

21 Rates and mean annual costs of consultations, tests, and prescribed items, were estimated by
22 BMI category at recruitment (18.5 to <20, 20 to <22.5, 22.5 to <25, 25 to <27.5, 27.5 to <30,

1 30 to <35, 35 to <40, and 40kg/m² or more).¹⁴ Percentage differences in rates and mean
2 annual costs per 2kg/m² higher BMI (a change in weight of approximately 5kg for a woman
3 of average height [162cm] in England) were calculated for women with a BMI above
4 20kg/m², both overall and, in the case of prescriptions, by category of therapeutic use. All
5 models were estimated using quasi-likelihood generalised linear models with a log-link and
6 Poisson-like variance allowing for overdispersion.

7 In all models, further adjustments were made for age (in five-year bands), region of
8 recruitment, socioeconomic status,¹⁵ parity, age at birth of first child, smoking, alcohol
9 intake, educational qualifications, financial year, and the proportion of each year with
10 contributed data. Missing values for any of the adjustment variables ($\leq 5\%$ for all variables)
11 were assigned to a separate category for that variable.

12 Cluster-robust standard errors were estimated in all models to account for the lack of
13 independence between outcomes for a given individual across years of follow-up. To
14 facilitate comparisons between any two BMI categories, even when neither is the reference
15 category, group-specific 99% CIs were derived from the variance of the logarithm of the
16 relative risks in each category.¹⁶

17 Estimates of mean annual rates and costs were standardised to the participants contributing to
18 the analysis based on the variables controlled for in regression. Annual costs were projected
19 to the whole population of 6.6 million women aged 55-79 years in England in 2013 using the
20 data on distribution of women by self-reported BMI from the Health Survey for England.^{17,18}
21 99% confidence intervals were estimated by randomly simulating model parameters 10,000
22 times (based on the point and variance estimates from the Million Women Study), and
23 applying the bootstrap percentile method to generate the confidence interval limits.

1 We conducted sensitivity analyses to test the associations between the BMI of women and
2 annual costs of consultations, tests, and prescriptions were estimated; including women with
3 a history of cancer at baseline; including all years of follow-up from recruitment; excluding
4 women with BMI $>50\text{kg/m}^2$; restricting the analysis to never-smokers; and excluding
5 participants with self-reported heart disease or stroke at recruitment. Estimates of percentage
6 differences in annual costs per 2kg/m^2 higher BMI were additionally estimated after replacing
7 self-reported BMI from the Million Women Study with the mean measured values of BMI
8 within each category of self-reported BMI from the Health Survey for England (Table S6).¹⁷

9 Annual costs were also estimated within subgroups of women defined by age at the start of
10 each annual period, and by smoking status, alcohol intake, strenuous exercise, socioeconomic
11 status, and educational qualifications at recruitment. Heterogeneity of proportional increases
12 in annual costs between categories of each subgroup was assessed using a chi-squared test.

13 An exploratory analysis was undertaken to study the extent to which the primary care costs
14 attributable to excess weight might be explained by diabetes. This is given as the difference
15 between the estimated proportion of excess weight-attributable costs from the primary
16 analysis and that derived from a model with diabetes status added as a covariate. Diabetes
17 was identified using self-reported diabetes status in the Million Women Study, and primary
18 care and hospital records (Statistical Appendix). A woman was deemed to have diabetes in
19 the annual period in which evidence for diabetes was first encountered and in all subsequent
20 years.

21 All analyses were conducted using R 3.3.3. Further details of methods are available in the
22 statistical appendix. Computer code is available from the corresponding author upon request.

1 **RESULTS**

2 The 69,440 women included in the main analysis were followed in CPRD for an average of
3 6.0 years from April 2006 (11.1 years from recruitment into the MWS) [Table 1]. Their mean
4 age was 56.0 years (SD 4.8) at recruitment and 64.2 (SD 5.2) years at the start of the analysis
5 period (April 2006 or later). At recruitment 47% of women had a BMI <25kg/m², 36% were
6 overweight (BMI 25 to ≤30kg/m²), and 17% were obese (BMI ≥30kg/m²). Women who were
7 overweight or obese tended to be of lower socioeconomic status and were less likely to do
8 any strenuous exercise, drink alcohol, or be current smokers, but were more likely to be
9 former smokers.

10 Mean rates and mean annual costs of consultations were lowest for women with BMI 20 to
11 <22.5kg/m², at 7.0 consultations per year (99% CI 6.8-7.1) and £288 per year (280-295),
12 respectively. Women with a BMI of ≥40kg/m² had an average of 11.1 consultations per year
13 (10.3-11.9) at a mean cost of £473 per year (441-506) [Table 2, Figure 1]. Mean annual rates
14 and costs of prescription medications were also lowest for women with BMI 20 to <22.5
15 kg/m² at 27.0 prescribed items per year (26.0-27.9) and £227 per year (216-237) respectively,
16 and rose to 69.2 items (63.6-74.8) and £587 (525-648) for women with BMI ≥40kg/m².
17 Participants had on average 8.4 diagnostic or monitoring tests per year (standard deviation
18 [SD] 23.0) at a cost of £53 per year (SD 166), but there was no evidence of an association
19 with BMI. For each 2kg/m² higher BMI above 20kg/m², the annual consultation and
20 prescription costs for women were 5.2% (4.8-5.6) and 9.9% (9.2-10.6) higher, respectively.
21 Annual prescription costs were elevated among women with BMI of 18.5 to <20kg/m² (£256
22 per year, 231-280) compared to BMI 20 to <22.5kg/m², but consultation and test costs were
23 similar.

1 Estimates of percentage differences in annual costs of primary care consultations,
2 prescriptions and diagnostic tests by BMI were not affected by the inclusion of women with
3 previous cancer, the exclusion of women with BMI $\geq 50\text{kg/m}^2$ or with previous heart disease
4 or stroke, or when using imputed data to account for measurement error in BMI derived from
5 self-reports (Tables S7-9). For annual consultation costs, estimates were also unaffected by
6 the inclusion of outcome data prior to 1 April 2006 or restriction to women who had never
7 smoked. The inclusion of outcome data prior to 1 April 2006 led to marginally smaller
8 percentage differences in annual prescription costs for women with higher BMIs, while
9 restriction to never smokers increased the estimated association.

10 The percentage differences in annual costs per 2kg/m^2 higher BMI above 20kg/m^2 were
11 similar between subgroups of women defined by smoking behaviour, alcohol consumption,
12 socioeconomic status, and education (Figures S1-3). There was some statistical heterogeneity
13 between different age groups for both consultation and prescription costs, with somewhat
14 smaller increases among older women, and, for prescription costs only, a somewhat smaller
15 association for physically active individuals compared to the inactive.

16 Extrapolating from the Million Women Study results to all 6.6 million women aged 55-79
17 years in England in 2013, total annual consultation and prescription costs were estimated to
18 be £2.2billion and £1.9billion, respectively (Table 3). 11% (£229million) of annual
19 consultation costs and 20% (£384million) of total annual prescription costs were attributable
20 to excess weight. Of the total excess weight attributable annual consultation and prescription
21 costs, around 30% were among women who were overweight but not obese, and 38% among
22 those with grade 1 obesity (BMI 30 to $<35\text{kg/m}^2$).

1 Excess weight was associated with higher prescription costs for most categories of
2 therapeutic use (Figure 2; Figure S4; Table S10). Of the £384 million annual prescription
3 medication costs attributed to excess weight among women aged 55-79 years in England,
4 £102million (27% of costs attributable to excess weight) was for drugs in diabetes,
5 £73million (19%) for circulatory system medications, and £51million (13%) for analgesics.
6 Drugs for hypertension and heart failure (£14million), anticoagulants and protamine
7 (£17million), and lipid-regulation (£15million), each accounted for around 20% of the excess
8 weight-attributable costs for the circulatory system.

9 Diabetes was self-reported at recruitment into the study by 1692 participants (3%). By the
10 end of follow-up, and as further indicated in primary and secondary healthcare data, 8,226
11 (12%) had some evidence of diabetes. We estimated that diabetes was associated with 37% of
12 consultation costs and 47% of prescription costs attributed to excess weight.

13

1 **DISCUSSION**

2 This analysis demonstrates the impact of excess weight on healthcare use by women aged
3 over 50 years in the UK. Higher BMI is associated with higher annual rates and costs of
4 primary care consultations and prescription medications, but not diagnostic and monitoring
5 tests. Among all women in England aged 55-79 years, excess weight accounted for 11% of
6 total annual consultation costs and 20% of annual prescription costs, of which 27% were for
7 diabetes drugs, 19% for circulatory system drugs, and 13% for analgesics.

8 A recent systematic review identified 18 individual participant data studies that estimated
9 prescription medication costs in relation to BMI, with sample sizes ranging from 2,244 to
10 17,703.¹⁹ Compared to adults with healthy weight, annual costs were, on average, 18% and
11 64% higher for overweight and obese adults, respectively. The corresponding estimates in our
12 study are somewhat larger, at 23% and 79%. In the MWS, analgesics and drugs for diabetes
13 and circulatory disease accounted for about 30% of all prescription costs, but almost 60% of
14 the costs attributable to excess weight, with drugs for diabetes the largest contributor. Few
15 other studies estimated medication costs in relation to BMI for different therapeutic uses;
16 those that did also tended to find the strongest proportional effects of high BMI on costs for
17 diabetes and cardiovascular medications, and analgesics, but with cardiovascular medications
18 contributing the greatest proportion of excess costs associated with overweight and obesity.²⁰⁻

19 ²⁴ The differences in estimates in our study compared to previous studies, which were based
20 mainly on US populations, are likely to reflect an older average age of participants in the
21 Million Women Study, and differences in healthcare systems, with varying accessibility of
22 healthcare, clinical practice, and prices for medications.^{7,25}

1 The lack of association between diagnostic and monitoring test costs and excess weight is
2 surprising and has not been previously reported. Given the greater prevalence of ill health and
3 frequency of consultations among women who are overweight or obese, one interpretation is
4 that these women are proportionally less likely to be offered diagnostic tests. This is a
5 concern and warrants further investigation since it may lead to delayed diagnosis and
6 exacerbate avoidable morbidity.

7 Few studies have estimated primary care consultation costs in relation to BMI and previous
8 studies were based on small sample sizes (500 to 3,000 participants)^{24,26-30}. Estimates of the
9 relative costs associated with obesity compared to healthy weight varied greatly from a 25%
10 reduction²⁶ to a 160% increase²⁷. Again, most studies used data from the US, where the
11 primary care system differs substantially from that in the UK.⁸ The few studies that reported
12 costs separately for diagnostic tests reported marginally higher costs with higher BMI^{26,31}.

13 Evidence of the associations between primary care costs and BMI were mostly similar in
14 population subgroups. There was some evidence of weaker associations among older adults,
15 with each unit higher BMI associated with 45% and 36% higher annual consultation and
16 prescription costs, respectively, in women aged less than 65 years compared to women 70
17 years or older. This is consistent with previous studies of associations between BMI and
18 mortality and hospital admissions.^{3,32} This could be a result of changes to body composition
19 in older adults, who tend to have less fat-free mass, or a consequence of reverse causality due
20 to higher rates of comorbidities in older adults.³³ Associations were also about 20% smaller
21 for physically active adults compared to inactive adults for prescription costs, although no
22 difference was observed for consultation costs. Differences in healthcare use associated with
23 excess weight by level of physical activity could arise because physical activity offsets some
24 of the adverse health effects of excess weight or because of preferences for lifestyle

1 modifications over pharmacological treatment for conditions like diabetes or cardiovascular
2 disease, but these hypotheses cannot be conclusively assessed in these data.

3 The projection of results from this study to all women aged 55-79 years in England assumes
4 that the distribution of characteristics within BMI categories is similar among women in the
5 general population and the study population. Study participants were representative of
6 women attending breast cancer screening during the recruitment period of the study³⁴, they
7 were more likely to come from less deprived areas and to have a current prescription for
8 hormone replacement therapy, but did not differ in terms of age or recent prescriptions for
9 various other medications.³⁵ Differences between women who participated in the study and
10 those who did not could result in a small bias to the estimated associations, but this would not
11 be expected to substantially change our findings.

12 Our findings are based on observational data and we have made efforts to deal with
13 confounding using statistical adjustment, and with reverse causality by excluding the first
14 five years of follow-up after recruitment. However, residual biases may remain. BMI was
15 derived from self-reported height and weight and may systematically underestimate true
16 BMI,³⁶ but BMI derived from self-reported height and weight in the Million Women Study is
17 closely correlated with BMI derived from measured height and weight nine years after
18 recruitment, and is suitable to accurately estimate linear associations.³⁷ We also excluded
19 women with missing height or weight. Although women with missing data may differ from
20 women with complete data, the proportion of women excluded was small, and we would not
21 expect their exclusion to make an appreciable difference to the estimated associations.

22 Estimates in this study reflect clinical practice in England during the period of study follow-
23 up, including clinical decisions and prescription guidelines. However, clinical practice varies

1 over time in response to a number of factors including new drugs and technologies, patent
2 expirations, and new medical evidence.³⁸ In other populations or at other times, the estimated
3 associations between BMI and costs might differ. Costs of prescription medications also do
4 not include the dispensing fee paid to pharmacists or any savings to the NHS from wholesale
5 purchase or special arrangements with manufacturers.

6 Our findings of higher primary care use and costs with higher BMI complement previous
7 results from the Million Women Study reporting higher hospital admissions rates and costs
8 with higher BMI in middle aged and older women in England, and emphasise the impact of
9 excess weight on the health of women⁶. Previous research has suggested that population
10 ageing has contributed to the increasing workload in primary care, but there are also increases
11 in age-sex standardised rates.³⁹ Our research suggests that rising rates of obesity are also
12 likely to be an important contributor. The finding that two-thirds of excess-weight
13 attributable costs were incurred among women who were overweight or mildly obese (BMI
14 $<35\text{kg/m}^2$) makes a case for clearer signposting to treatment services or advice for self-
15 management to all women with excess weight.^{40,41} Weight loss would benefit women through
16 improved health and would be expected to decrease healthcare usage. The results should also
17 be useful to healthcare commissioners and planners making investment and prioritisation
18 decisions, particularly in relation to local needs and expectations of changes in overweight
19 and obesity rates. Qualitative research which engages with women may reveal additional
20 opportunities to enhance healthcare services for this group. Future research should also
21 investigate the associations in men and in younger individuals, and seek to identify the
22 contributions of different health conditions to the consultation costs that are attributable to
23 excess weight.

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1 **Million Women Study Collaborators**

2 The Million Women Study Co-ordinating Centre staff are as follows: Hayley Abbiss, Simon
3 Abbott, Rupert Alison, Miranda Armstrong, Krys Baker, Angela Balkwill, Isobel Barnes,
4 Valerie Beral, Judith Black, Roger Blanks, Kathryn Bradbury, Anna Brown, Benjamin
5 Cairns, Dexter Canoy, Andrew Chadwick, Dave Ewart, Sarah Ewart, Lee Fletcher, Sarah
6 Floud, Toral Gathani, Laura Gerrard, Adrian Goodill, Jane Green, Lynden Guiver, Alicia
7 Heath, Darren Hogg, Michal Hozak, Isobel Lingard, Sau Wan Kan, Nicky Langston, Kath
8 Moser, Kirstin Pirie, Alison Price, Gillian Reeves, Keith Shaw, Emma Sherman, Rachel
9 Simpson, Helena Strange, Sian Sweetland, Sarah Tipper, Ruth Travis, Lyndsey Trickett,
10 Anthony Webster, Clare Wotton, Lucy Wright, Owen Yang, Heather Young.

11 The Advisory Committee are: Emily Banks, Valerie Beral, Lucy Carpenter, Carol Dezateux,
12 Jane Green, Julietta Patnick, Richard Peto, Cathie Sudlow.

References

1. NCD Risk Factor Collaboration. Trends in adult body-mass index in 200 countries from 1975 to 2014: a pooled analysis of 1698 population-based measurement studies with 19.2 million participants. *Lancet* 2016; **387**(10026): 1377-96.
2. Guh DP, Zhang W, Bansback N, Amarsi Z, Birmingham CL, Anis AH. The incidence of co-morbidities related to obesity and overweight: a systematic review and meta-analysis. *BMC public health* 2009; **9**: 88.
3. Global BMI Mortality Collaboration. Body-mass index and all-cause mortality: individual-participant-data meta-analysis of 239 prospective studies in four continents. *Lancet* 2016; **388**(10046): 776-86.
4. Luppino FS, de Wit LM, Bouvy PF, et al. Overweight, obesity, and depression: a systematic review and meta-analysis of longitudinal studies. *Arch Gen Psychiatry* 2010; **67**(3): 220-9.
5. Kent S, Fusco F, Gray A, Jebb SA, Cairns BJ, Mihaylova B. Body mass index and healthcare costs: a systematic literature review of individual participant data studies. *Obes Rev* 2017; **18**(8): 869-79.
6. Kent S, Green J, Reeves G, et al. Hospital costs in relation to body-mass index in 1.1 million women in England: a prospective cohort study. *The Lancet Public Health* 2017; **2**(5): e214-e22.
7. Squires D, Anderson C. U.S. health care from a global perspective: spending, use of services, prices, and health in 13 countries. *Issue Brief (Commonw Fund)* 2015; **15**: 1-15.
8. Roland M, Guthrie B, Thome DC. Primary medical care in the United kingdom. *J Am Board Fam Med* 2012; **25** Suppl 1: S6-11.
9. Chisholm J. The Read clinical classification. *BMJ* 1990; **300**(6732): 1092.
10. Joint Formulary Committee. British National Formulary (online). 2017. <http://www.medicinescomplete.com> (accessed 03 April 2017).
11. Curtis L, Burns A. Unit Costs of Health & Social Care 2016. Kent. Person Social Services Research Unit, 2017.
12. Department of Health. NHS reference costs: financial year 2015-16. <https://www.gov.uk/government/publications/nhs-reference-costs-financial-year-2011-to-2012> (accessed 03 April 2017).
13. NHS Business Services Authority. Prescription Cost Analysis (PCA) Data. 2017. <http://www.nhsbsa.nhs.uk/PrescriptionServices/3494.aspx>.
14. World Health Organisation. Obesity: Preventing and Managing the Global Epidemic. Geneva, Switzerland. World Health Organisation, 2000.
15. Townsend P, Phillimore P, Beattie A. Health and Deprivation: Inequality and the North. London. Croom Helm, 1988.
16. Plummer M. Improved estimates of floating absolute risk. *Statistics in medicine* 2004; **23**(1): 93-104.

17. Health and Social Care Information Centre. Health Survey for England: health, social care and lifestyles. <http://www.hscic.gov.uk/healthsurveyengland> (accessed 31 July 2015).
18. Office for National Statistics. Population Estimates for UK, England and Wales, Scotland and Northern Ireland, Mid-2013. 2014. <http://www.ons.gov.uk/ons/publications/re-reference-tables.html?edition=tcm%3A77-322718> (accessed 28 April 2015).
19. Kent S, Fusco F, Gray A, Jebb SA, Cairns BJ, Mihaylova B. Body mass index and healthcare costs: a systematic literature review of individual participant data studies. *Obes Rev* 2017.
20. Esposti ED, Sturani A, Valpiani G, et al. The relationship between body weight and drug costs: An Italian population-based study. *Clinical Therapeutics* 2006; **28**(9): 1472-81.
21. Narbro K, Agren G, Jonsson E, Naslund I, Sjostrom L, Peltonen M. Pharmaceutical costs in obese individuals: Comparison with a randomly selected population sample and long-term changes after conventional and surgical treatment: The SOS intervention study. *Archives of Internal Medicine* 2002; **162**(18): 2061-9.
22. Ostbye T, Stroo M, Eisenstein EL, Peterson B, Dement J. Is overweight and class i obesity associated with increased health claims costs? *Obesity* 2014; **22**(4): 1179-86.
23. Stuart B, Lloyd J, Zhao L, Kamal-Bahl S. Obesity, disease burden, and prescription spending by community-dwelling Medicare beneficiaries. *Curr Med Res Opin* 2008; **24**(8): 2377-87.
24. Thompson D, Brown JB, Nichols GA, Elmer PJ, Oster G. Body mass index and future healthcare costs: a retrospective cohort study. *Obes Res* 2001; **9**(3): 210-8.
25. Jick H, Wilson A, Wiggins P, Chamberlin DP. Comparison of prescription drug costs in the United States and the United Kingdom, Part 1: statins. *Pharmacotherapy* 2012; **32**(1): 1-6.
26. Bertakis K, Azari R. Obesity and the use of health care services. *Obes Res* 2005; **13**(2): 372-9.
27. Martin BC, Church TS, Bonnell R, Ben-Joseph R, Borgstadt T. The impact of overweight and obesity on the direct medical costs of truck drivers. *J Occup Environ Med* 2009; **51**(2): 180-4.
28. McHugh S, O'Neill C, Browne J, Kearney PM. Body mass index and health service utilisation in the older population: Results from the Irish Longitudinal Study on Ageing. *Age Ageing Journal Translated Name Age and Ageing* 2015; **44**(3): 428-34.
29. Tigbe WW, Briggs AH, Lean ME. A patient-centred approach to estimate total annual healthcare cost by body mass index in the UK Counterweight programme. *Int J Obes (Lond)* 2013; **37**(8): 1135-9.
30. Wolfenstetter SB. Future direct and indirect costs of obesity and the influence of gaining weight: Results from the MONICA/KORA cohort studies, 1995-2005. *Economics and Human Biology* 2012; **10**(2): 127-38.
31. Detournay B, Fagnani F, Phillippo M, et al. Obesity morbidity and health care costs in France: an analysis of the 1991-1992 Medical Care Household Survey. *Int J Obes Relat Metab Disord* 2000; **24**(2): 151-5.

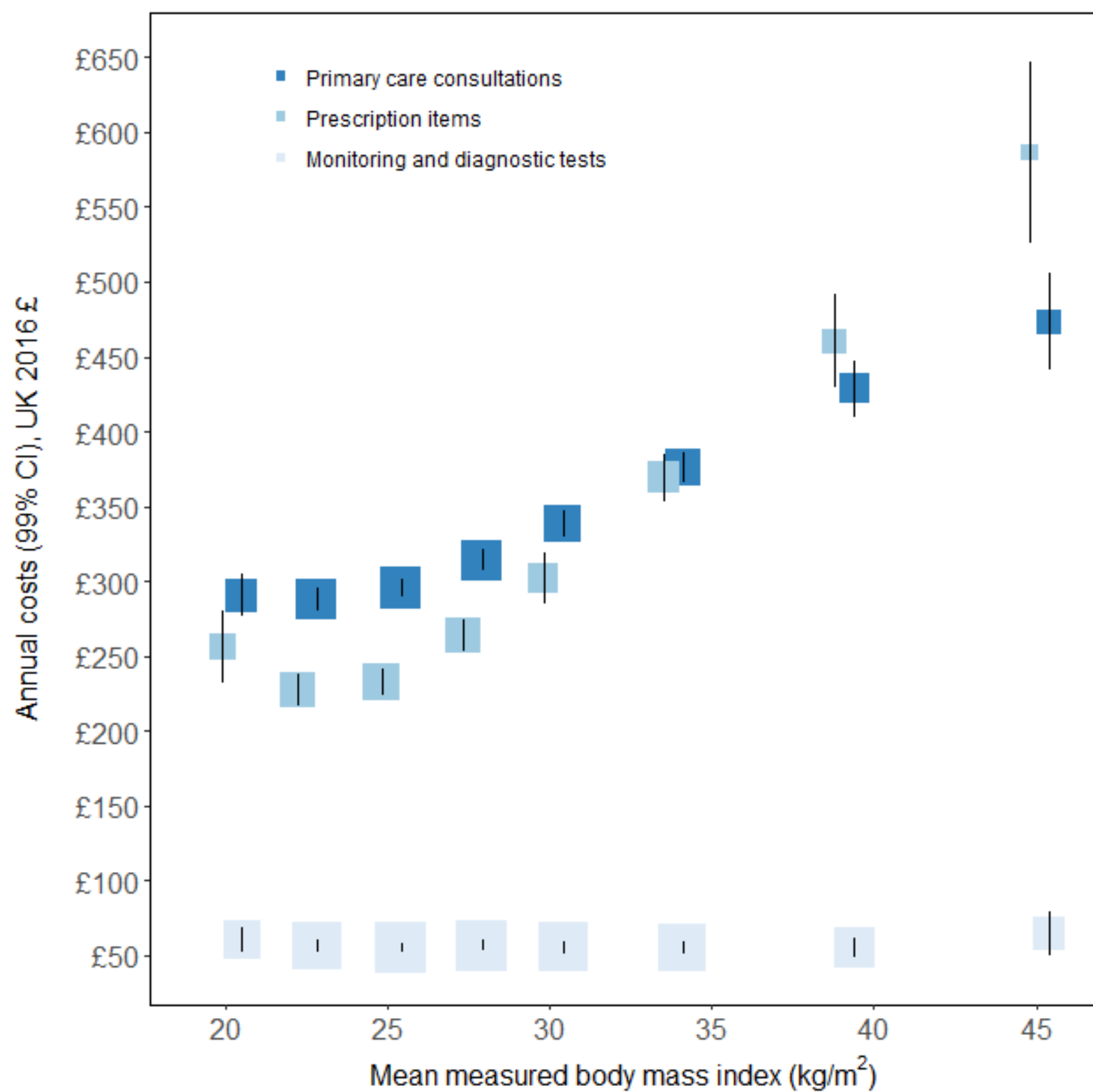
32. Korda RJ, Liu B, Clements MS, et al. Prospective cohort study of body mass index and the risk of hospitalisation: findings from 246361 participants in the 45 and Up Study. *Int J Obes (Lond)* 2013; **37**(6): 790-9.
33. Inelmen EM, Sergi A, Coin A, Miotto F, Peruzza S, Enzi G. Can obesity be a risk factor in elderly people? *Obesity Reviews* 2003; **4**(3): 147-55.
34. The Million Women Study Collaborative Group. The Million Women Study: design and characteristics of the study population. The Million Women Study Collaborative Group. *Breast Cancer Res* 1999; **1**(1): 73-80.
35. Banks E, Beral V, Cameron R, et al. Comparison of various characteristics of women who do and do not attend for breast cancer screening. *Breast Cancer Res* 2002; **4**(1): R1.
36. Spencer EA, Roddam AW, Key TJ. Accuracy of self-reported waist and hip measurements in 4492 EPIC-Oxford participants. *Public health nutrition* 2004; **7**(6): 723-7.
37. Wright FL, Green J, Reeves G, Beral V, Cairns BJ, on behalf of the Million Women Study collaborators. Validity over time of self-reported anthropometric variables during follow-up of a large cohort of UK women. *BMC Med Res Methodol* 2015; **15**: 81.
38. O'Keeffe AG, Nazareth I, Petersen I. Time trends in the prescription of statins for the primary prevention of cardiovascular disease in the United Kingdom: a cohort study using The Health Improvement Network primary care data. *Clin Epidemiol* 2016; **8**: 123-32.
39. Hobbs FD, Bankhead C, Mukhtar T, et al. Clinical workload in UK primary care: a retrospective analysis of 100 million consultations in England, 2007-14. *Lancet* 2016; **387**(10035): 2323-30.
40. Hartmann-Boyce J, Jebb SA, Fletcher BR, Aveyard P. Self-help for weight loss in overweight and obese adults: systematic review and meta-analysis. *Am J Public Health* 2015; **105**(3): e43-57.
41. Hartmann-Boyce J, Johns DJ, Jebb SA, Summerbell C, Aveyard P, Behavioural Weight Management Review G. Behavioural weight management programmes for adults assessed by trials conducted in everyday contexts: systematic review and meta-analysis. *Obes Rev* 2014; **15**(11): 920-32.

Figure 1. Annual primary care consultation and prescription costs per person by category of body mass index

The standardised estimates of mean annual costs (in UK 2016 prices) are adjusted for age, region of recruitment, deprivation, educational qualifications, parity, age at birth of first child, smoking, alcohol intake, financial year, and proportion of year with contributed data. Annual costs are plotted against mean measured BMI (with a small offset to avoid overlapping CIs) within categories of self-reported BMI from the combined 2012 and 2013 Health Surveys for England (Supplementary Table 5). The area of each square is inversely proportional to the variance of that estimate. The error bars show 99% CI.

Figure 2. Annual prescription costs attributable to excess weight among women aged 55 to 79 years in England, by category of therapeutic use

Medications were categorised by therapeutic use (defined by BNF chapters or sections), and ordered here according to their contribution to overweight and obesity attributable costs. These estimates were derived by applying the estimates of excess costs by BMI category for each therapeutic use category from the Million Women Study analysis to women aged 55 to 79 in England using the Health Surveys for England 2012 and 2013 to estimate the population level distribution of women by self-reported BMI category and ONS mid-2013 population estimates. Excess costs were calculated relative to a BMI category of 20-24.9, estimated as a weighted average of the estimates of the two sub-categories (20 to <22.5 and 22.5 to <25).



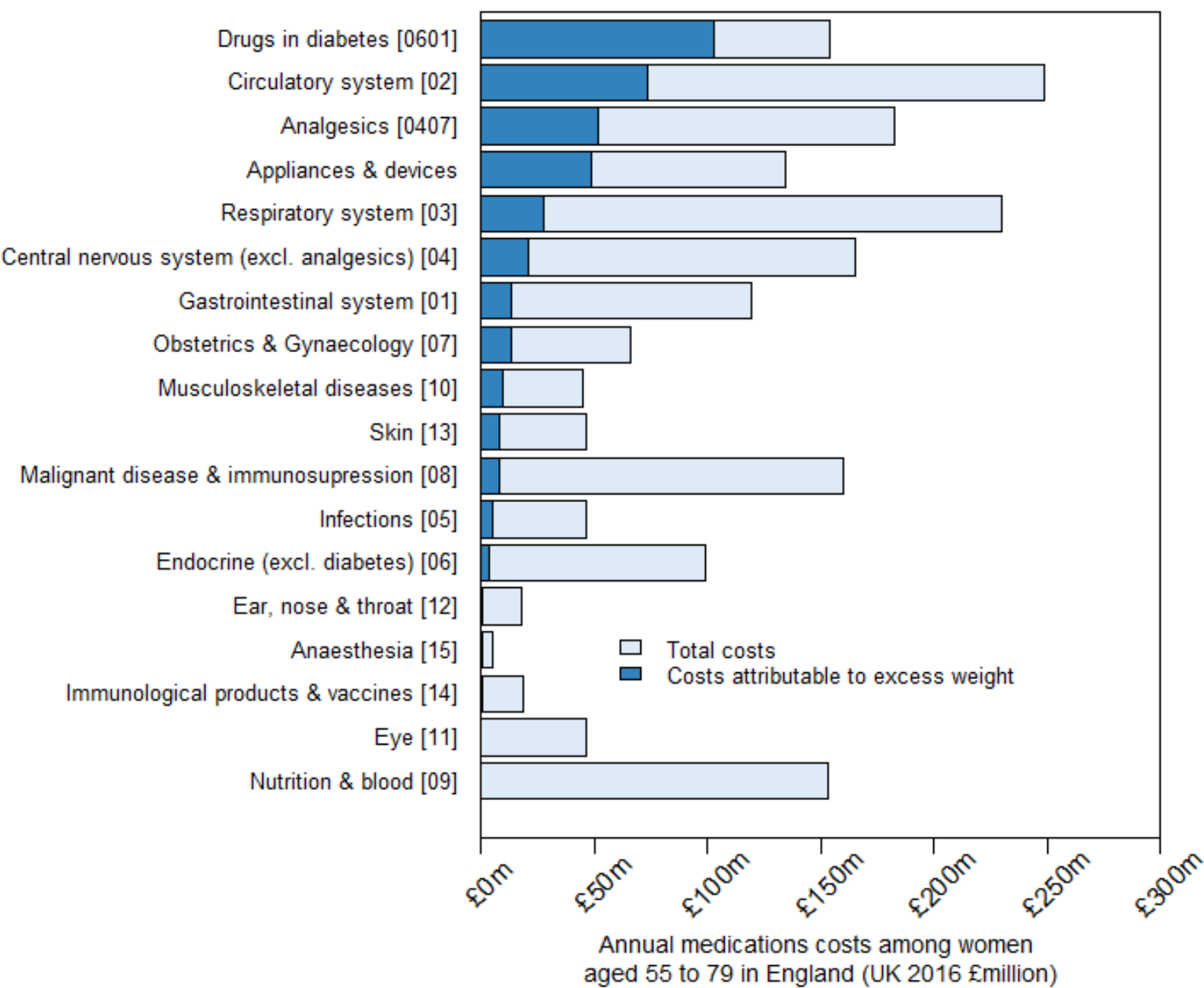


Table 1. Baseline characteristics and details of follow-up by category of body mass index

	Body mass index (kg/m ²) at recruitment into MWS								All women
	18.5 to <20	20 to <22.5	22.5 to <25	25 to <27.5	27.5 to <30	30 to <35	35 to <40	≥40	
Number of women	1,950	11,254	19,303	14,996	9,866	8,591	2,575	905	69,440
Characteristics at recruitment into MWS									
Body mass index, median (IQR)	19.4 (0.6)	21.5 (1.1)	23.8 (1.3)	26.1 (1.3)	28.6 (1.2)	31.8 (2.3)	36.6 (2.3)	42.3 (3.9)	25.3 (5.4)
Age, mean (SD)	55.8 (4.8)	55.6 (4.8)	55.9 (4.8)	56.3 (4.8)	56.3 (4.8)	56.3 (4.8)	55.8 (4.6)	55.7 (4.6)	56.0 (4.8)
Deprivation third in study population (%)									
Least deprived	35.5	39.8	39.3	36.0	34.2	30.1	27.7	23.5	36.1
Most deprived	31.8	26.7	26.7	30.1	32.6	36.3	42.4	47.5	30.5
Educational qualifications (%)									
No qualifications	36.0	33.5	38.1	42.7	46.8	50.6	53.6	57.1	41.9
Secondary or technical	45.4	48.6	47.0	44.5	41.6	39.4	38.3	34.7	44.5
Tertiary	18.5	17.8	14.9	12.8	11.6	10.0	8.0	8.2	13.6
Smoking status (%)									
Never	51.0	52.8	53.4	52.2	51.5	51.2	52.8	49.2	52.4
Former	19.8	25.3	27.9	29.1	31.1	32.9	34.1	37.7	28.9
Current	29.2	21.9	18.7	18.7	17.4	15.9	13.1	13.1	18.7
Current alcohol drinkers (%)	75.5	81.2	81.8	78.8	75.0	71.1	63.1	57.6	77.6
Exercise rarely or never (%)	17.3	14.4	15.8	19.1	23.5	28.9	33.1	41.6	20.0
With prior health conditions (%) ^a	21.2	18.8	20.5	24.3	28.3	33.7	39.7	46.5	24.9
Details of follow-up in CPRD from 1 April 2006									
Age ^b , mean (SD)	64.1 (5.2)	63.8 (5.1)	64.1 (5.2)	64.4 (5.2)	64.4 (5.2)	64.4 (5.1)	63.9 (5.0)	63.7 (5.0)	64.2 (5.2)
Years of follow-up (1,000s)	11.3	66.9	115.6	89.7	59.0	51.4	15.1	5.2	414.2
Total number of consultations (1,000s)	76	434	780	650	466	453	149	57	3,069
Total number of prescriptions items issued (1,000s)	309	1,631	3,144	2,926	2,296	2,479	881	383	14,051
Total number of tests (1,000s)	100	570	996	832	547	478	141	56	3,723

MWS=Million Women Study; IQR=Interquartile range; SD=standard deviation; CPRD=Clinical Practice Research Datalink

Percentages exclude participants with missing data on characteristics; percentage of missing data is less than 3% for all characteristics except for smoking status (5%)

^aAny of self-reported heart disease, stroke, diabetes, rheumatoid arthritis, osteoarthritis, osteoporosis or depression/anxiety

^bAge at the start of the analysis period, i.e. 1 April 2006 or, if later, the date from which their primary care practice provided data of sufficient quality for research.

Table 2. Annual rates and costs of consultations, tests, and prescription items issued, by body mass index

BMI category (kg/m ²)	Rate per person-year		Annual costs per person	
	Number per year	Difference in rate (%) ^a	Annual costs (2016 UK £)	Difference in costs (%) ^a
Primary care consultations				
18.5 to <20	7.0 (6.7, 7.3)	0.4% (-4.2, 5.2)	£290 (276, 304)	0.9% (-3.8, 5.8)
20 to <22.5 (reference)	7.0 (6.8, 7.1)	0.0% (-2.0, 2.0)	£288 (280, 295)	0.0% (-2.0, 2.1)
22.5 to <25	7.1 (7.0, 7.3)	2.7% (1.1, 4.2)	£296 (289, 302)	2.7% (1.2, 4.3)
25 to <27.5	7.5 (7.4, 7.7)	8.4% (6.6, 10.1)	£314 (307, 321)	9.1% (7.3, 10.9)
27.5 to <30	8.1 (7.9, 8.3)	16.7% (14.4, 19.0)	£338 (329, 347)	17.5% (15.1, 19.8)
30 to <35	9.0 (8.7, 9.2)	28.8% (26.1, 31.6)	£376 (366, 386)	30.7% (27.8, 33.5)
35 to <40	10.1 (9.7, 10.5)	45.0% (39.3, 50.9)	£428 (410, 447)	48.9% (42.9, 55.3)
≥40	11.1 (10.3, 11.9)	59.2% (48.9, 70.3)	£473 (441, 506)	64.5% (53.5, 76.3)
Diagnostic tests				
18.5 to <20	8.3 (7.2, 9.4)	3.3% (-9.5, 18.0)	£60 (52, 68)	6.7% (-6.0, 21.1)
20 to <22.5 (reference)	8.0 (7.5, 8.5)	0.0% (-5.8, 6.1)	£56 (52, 60)	0.0% (-5.4, 5.8)
22.5 to <25	8.1 (7.6, 8.5)	0.9% (-3.2, 5.2)	£55 (52, 58)	-2.0% (-6.0, 2.1)
25 to <27.5	8.6 (8.1, 9.1)	7.3% (2.4, 12.4)	£56 (53, 60)	0.4% (-4.2, 5.2)
27.5 to <30	8.6 (8.0, 9.1)	7.3% (1.3, 13.6)	£55 (51, 59)	-1.8% (-7.4, 4.1)
30 to <35	8.6 (8.0, 9.2)	7.0% (0.7, 13.8)	£55 (50, 59)	-2.6% (-8.6, 3.9)
35 to <40	8.6 (7.6, 9.6)	7.8% (-3.3, 20.2)	£55 (48, 62)	-2.4% (-13.1, 9.6)
≥40	10.0 (7.9, 12.2)	25.5% (1.3, 55.4)	£64 (50, 78)	14.4% (-8.0, 42.1)
Prescription items issued				
18.5 to <20	28.4 (26.2, 30.6)	5.4% (-2.2, 13.5)	£256 (231, 280)	12.9% (2.5, 24.3)
20 to <22.5 (reference)	27.0 (26.0, 27.9)	0.0% (-3.0, 3.1)	£227 (216, 237)	0.0% (-4.0, 4.2)
22.5 to <25	29.3 (28.5, 30.1)	8.7% (6.4, 11.1)	£233 (224, 241)	2.6% (-0.6, 5.8)
25 to <27.5	33.8 (32.8, 34.8)	25.4% (22.5, 28.3)	£264 (253, 274)	16.4% (12.7, 20.2)
27.5 to <30	39.2 (37.9, 40.5)	45.3% (41.4, 49.4)	£302 (285, 318)	33.1% (26.8, 39.7)
30 to <35	47.4 (45.9, 49.0)	76.0% (71.1, 81.0)	£369 (353, 385)	62.8% (56.7, 69.1)
35 to <40	57.0 (53.9, 60.1)	111.5% (100.4, 123.2)	£460 (429, 492)	103.0% (90.1, 116.9)
≥40	69.2 (63.6, 74.8)	156.5% (136.5, 178.3)	£587 (525, 648)	158.7% (134.1, 185.9)

BMI=body mass index. Values are means (99% confidence intervals).

^aDifferences are presented as percentage differences compared to BMI 20 to <22.5 kg/m², with floating confidence intervals.

All models are adjusted for age, region of recruitment, deprivation, educational qualifications, parity, age at first birth, smoking, alcohol intake, financial year, and proportion of year with contributed data.

Table 3. Annual primary care consultation and prescription costs attributed to excess weight among women aged 55 to 79 years in England

Body mass index (kg/m ²)	Number of women aged 55 to 79 in England (million)	Total annual costs (£million)	Costs attributed to excess weight	
			Absolute annual costs (£million) (99% CI)	Proportion costs attributed (%) (99% CI)
Primary care consultations				
<25	2.83	826	-	-
25-29.9	2.28	737	71 (60, 82)	10 (8, 11)
30-34.9	1.06	399	88 (80, 97)	22 (20, 24)
35-39.9	0.30	130	41 (36, 46)	32 (29, 34)
≥40	0.16	75	28 (24, 33)	38 (34, 42)
≥25 (all overweight and obesity)	3.80	1,340	229 (210, 248)	17 (16, 18)
Prescriptions items issued				
<25	2.83	661	-	-
25-29.9	2.28	636	112 (91, 132)	18 (15, 20)
30-34.9	1.06	392	147 (133, 162)	38 (35, 40)
35-39.9	0.30	139	70 (61, 79)	50 (47, 53)
≥40	0.16	92	56 (48, 65)	61 (57, 64)
≥25 (all overweight and obesity)	3.80	1,259	384 (352, 418)	31 (28, 33)

Estimates were derived by combining standardised estimates of annual costs per person (Table 2) and estimates of the number of women aged 55 to 79 in England by self-reported BMI category (Supplementary Table 4). See further details of methods in statistical appendix.